PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : E21B 15/00, G05B 19/404

A1

(11) International Publication Number: **WO 00/34617**

(43) International Publication Date: 15 June 2000 (15.06.00)

(21) International Application Number: PCT/SE99/02274

(22) International Filing Date: 7 December 1999 (07.12.99)

(30) Priority Data:
982668 9 December 1998 (09.12.98) FI

(71) Applicant *(for all designated States except US)*: SANDVIK AB; (publ) [SE/SE]; S–811 81 Sandviken (SE).

(72) Inventors; and

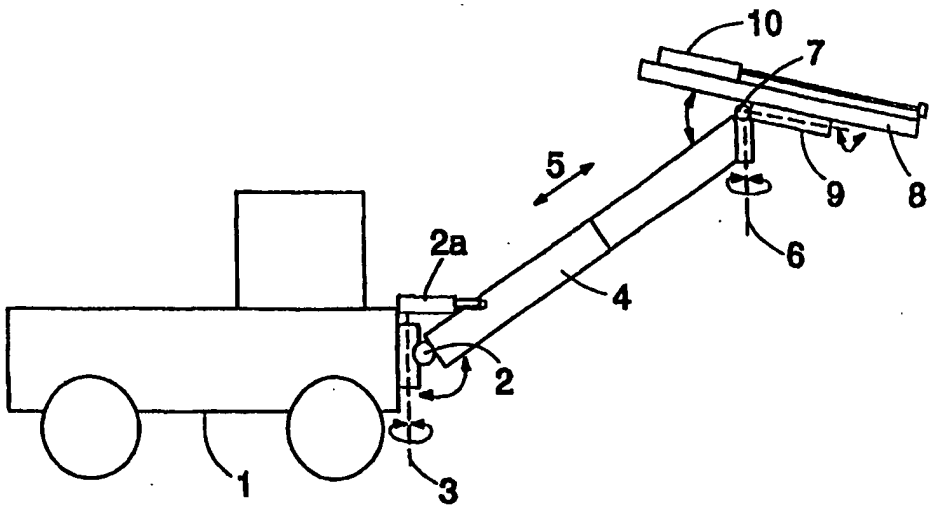
(75) Inventors/Applicants *(for US only)*: COOGAN, John [GB/FI]; Lapintie 9 B 24, FIN–33100 Tampere (FI). HEIKKOLA, Jussi [FI/FI]; Mikropolku 3 A 21, FIN–33720 Tampere (FI). SANERMA, Simo [FI/FI]; Iisakinkuja 3 as 1, FIN–37560 Lempäälä (FI).

(74) Agent: CARLSSON, Lars–Åke; Sandvik AB, Patent Dept., S–811 81 Sandviken (SE).

(81) Designated States: AU, CA, JP, NO, US, ZA, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD FOR CORRECTING POSITIONING ERRORS IN ROCK DRILLING, AND A ROCK DRILLING EQUIPMENT



(57) Abstract

The invention relates to a method for correcting positioning errors in rock drilling, and a rock drilling equipment. Deviation of the boom (4) position from the theoretical position is measured as a function of the position of at least one boom joint (2, 3), the measured deviations are stored in the memory of the drilling rig, and when the boom (4) is positioned to the drilling position, its position is corrected on the basis of the stored deviation. The drilling equipment includes a memory for storing the deviations between the true position of the boom (4) and the theoretical position calculated on the basis of the joint sensor (2, 3) values, and a calculating device for correcting the boom (4) position on the basis of the deviations stored in the said memory.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

Method for correcting positioning errors in rock drilling, and a rock drilling equipment

The invention relates to a method for correcting positioning errors in rock drilling, where a boom, attached from one end to a carrier and turnable in relation to it about joints, and a rock drill, mounted turnable to the other end of the boom, are arranged in the drilling position for drilling a hole in a way that the boom is controlled using control devices of the drilling rig in relation to various movements until the boom is in its set position, wherein the deviation of the boom´s actual position from the calculated theoretical position is measured, and the boom´s position is corrected on the basis of the measured deviation

Further, the invention is related to a rock drilling equipment, with a carrier, a boom attached turnable about joints in relation to the carrier, a rock drill attached turnable to the other end of the boom, joint sensors indicating the positions of the various boom joints, and control devices for controlling the boom to the drilling position for drilling a hole.

Higher and higher precision is required of the operation of a rock drilling rig so that excavating could be made as economic as possible. Today, automatic drilling boom positioning and controlling devices are more often used with the purpose of enabling the holes to be drilled as precisely as possible at their intended positions. For practical controlling purposes, various types of joint sensors are attached to booms, and the aim is to take into account the geometrical dimensions of the booms and their kinematics as well as possible when calculating the drill position and direction. The problem with automatic control solutions realized in this manner is, however, that different types of deflections, clearances and other things causing error result in that the actual position of the drill bit may considerably differ from the position where it should be according to the plan.

US Patent 4,698,570 presents a solution where the aim is to correct errors of known equipment by dividing the operating range of the drilling boom, i.e. the reach of the boom in one carrier position, into squares and with a specific correction value assigned for each square in all directions of the co-ordinate

system. This is achieved in practice by setting the equipment to control the boom and the feed beam so that the drill bit is, in theory, at the centre of the square in question, after which the errors in the different directions have been measured and fed into the memory of the control equipment. In normal drilling use, the rig corrects the boom and feed beam positions in accordance with the square at which the intended hole position is located on the basis of the stored, fixed correction values of the square in question. The problem of this solution is that a tight grid must be used for the area to be drilled in order to get a sufficient number of correction data for the various boom positions. Further, as the drill bit can be positioned at one specific location using a number of different boom positions, a correction system based on the mere location of the drill bit is unable to compensate the different errors based on different boom positions and, thus, the intended precision is not reached.

The object of this invention is to provide a method and equipment, to avoid the errors of the known solutions and to reliably, and as easily and simply as possible, correct the errors caused by boom movements. The method according to the invention is characterized in that the deviation of the boom position from the theoretical position is measured at predetermined intervals as a function of the position of at least one boom joint, that the measured deviations are stored in the memory of the drilling rig, and that when the boom and the rock drill are positioned to the drilling position, the position is corrected on the basis of the stored deviation that corresponds to the position of the joint corresponding to the said drilling position.

The drilling equipment according to the invention is characterized in that it includes a memory device for storing the deviations between the true position of the boom and the theoretical position calculated on the basis of the joint sensor values as a function of the turning angle of at least one boom joint, and a calculating device for correcting the boom position on the basis of the deviations stored in the said memory device and corresponding to the value indicated by the joint sensor of the said joint.

The essential idea of the invention is to determine at least the errors of those of the different boom movements mainly causing an error, i.e. the

deviations between the true boom position and the theoretical position, calculated on the basis of the movement sensor, primarily of the set value indicated by the angle sensor of the turning angles, corresponding to the movement in question, one movement at a time or two movements at a time practicably in relation to the movement at suitable intervals and by correcting the boom position on the basis of the errors, i.e. deviations, measured in relation to movement or movements in question and for each movement separately. This enables, for instance, the defining of errors on the basis of the turning angles between the boom and the carrier, and on the basis of the rotation angles of the rotation mechanism of the feed beam, i.e. so called roll-over mechanism. Still, the essential idea of one preferred embodiment of the invention is that when the errors at set values positioned at suitable intervals have been determined and stored in the memory of the control device, a mathematical approximation regarding the alteration of the error is formed between two measured points when moving from one point to the other whereby, when a position is located in such an area, sufficiently accurate approximations for correcting the error are available.

The advantage of a method according to the invention is that already by defining the errors as a function of the main joints and their turning angles, relatively accurate information on the errors of the boom position is available and, thus, it is easy to correct the error in the various boom and feed beam positions by compensating just the errors caused by the most significant sources of error. This means that a relatively small amount of correcting data need to be fed into the memory of the control device, which makes controlling easier to carry out. Further, when the change of deviation between the measured points is calculated mathematically, a sufficiently accurate approximation of the error between the measured values is always obtained, and the total error and the resulting required compensation can be calculated using error definitions made at relatively large intervals. This diminishes the number of measuring points required for the definition of deviation.

The invention will be described more closely by the attached drawing, where

Figure 1 is a schematic view of a boom used in a rock drilling rig, and

Figure 2 schematically presents the defining of error as a function of one joint, e.g. the turning angle of the joint between the boom and the carrier of the rock drilling rig.

Figure 1 schematically presents a rock drilling rig with a carrier 1 and a boom 4 pivotally connected about joints 2 and 3. The boom can be turned in relation to the carrier and other boom movements can be accomplished using various actuators of known type, such as the hydraulic cylinder 2a schematically presented in the drawing. Such actuators that are of a known type as such and self-evident to the person skilled in the art, are not explained in any detail in the drawing. The boom can be of any known type or of a construction that can be constructed or assembled in a normal way. The boom can consist of one or more parts that can, during boom movements, be turned at the joints or the axles between them or, for instance, be moved linearly in relation to one another. In this patent application and patent claims, boom movements mean all these turning, rotating, or linear movements between the boom and the carrier, the different parts of the boom, as well as between the boom and the feed beam attached to its end. The boom 4 can be, for instance, a telescopic boom whose length can be adjusted longer or shorter in the direction indicated by the arrow 5. At the top end of the boom 4, there are the turning joints 6 and 7 around which the feed beam 8 can be turned in relation to the boom end. Further, it may include a rotating device 9 to which the feed beam 8 is attached parallel to the axis of the rotating device, so that the feed beam 8, and the rock drill 10 moving along it, can be rotated around the said axis while their direction remains unchanged.

Figure 2 schematically presents how the error occurring at different angle positions of a single joint, exemplified in this case by the horizontal swing joint between the boom and the carrier, can be defined according to the invention. For this purpose, the turning angle is divided into ten sectors so that, in theory, when a command is given to the control device to turn the boom to a certain angle, it will be positioned precisely to the defined angle.

In order to determine the error, the boom is turned with the aid of the control device, for instance, one defined angle sector at a time, which is then carried out on automatic rigs by the control device on the basis of the signals given by the movement sensors, in this case the angle sensors. Correspondingly, on non-automatic rigs, the operator uses the manoeuvring controls to turn the boom in the desired direction until the intended angle is reached.

In each boom position, the deviation of the boom position from the theoretical position is measured, and the errors are stored in the memory. This gives the upper error diagram, marked with A, presented in Figure 2, which is stored for use in the memory of the control equipment i.e. the control device that is usually a single unit. The deviations of boom position are simple to express as deviation of the position of the rock drill tool, i.e. the drill bit, and as deviation of the rock drill drilling direction, i.e. the axis of the drill steel between the rock drill and the drill bit. Defined in this way, the error is unambiguous and correction of the error in the co-ordinate system related to the rock is easy to accomplish. In the case represented in diagram A, a fixed error value is used in a certain span, whereby the positive or negative error value, i.e. the deviation, of a measuring point indicated by a dot is used for correction on both sides of the measuring point halfway between two measuring points. In order to obtain some kind of probable value between the accurate measuring points, an error correction curve is formed like, for instance, the one in diagram B of Figure 2 so that the error values between adjacent turning angles are combined and the error deviation is calculated on the basis of this. A linear change is the simplest to use, whereby a mathematically straight line between the error values is calculated when moving from one position to the other and, on the basis of the turning angle, the approximation for the error. This is illustrated in diagram B of Figure 2 by the straight lines drawn between the measured dots shown in diagram A of Figure 2. Instead of straight lines, various kind of non-linear approximations can, naturally, be used but, in most cases, this is not necessary.

When the deviations according to the joint turning angle, i.e. the errors, have been defined related to one joint axis, they are then defined in a

corresponding manner for the turning angles of the other joint axis of the same joint. Further, if the feed beam is mounted to the end of the boom using a rotation mechanism, the errors caused by the turning angles of the rotation mechanism are measured and stored in the memory. Accomplished in this way, the most significant causes of error can be taken into consideration, and the final error affecting the position of the drill bit can be defined by adding up the error values of each component. This provides an effective and reliable control method with a relatively small number of measured error values, with the said method taking into consideration the effect of the various components of the boom on the error of the drill bit position as a result of the various positions of the boom and its parts. In practice, a simpler way to correct the error is to correct the error emerging as a function of each turning movement on the basis of the measured deviation values corresponding to each movement, whereby the result is that the drill bit is due to the error corrections quite accurately in its designed location and the drilling axis in the desired direction.

During actual drilling operation, whereby the deviations have been separately measured and stored in advance in the memory organs of the drilling rig's control devices, the correction of the position on rigs with automatic control is realized automatically so that when the control devices starts controlling the boom with the aim to move it to the desired drilling location, an error correction related to each movement is carried out automatically so that the calculated set value for the boom position is corrected on the basis of the deviation values stored in the memory. In this way, the whole correction of drilling and positioning error can be done fully automatically for each hole to be drilled according to a drill plan made pursuant to any generally applied method. In manual implementations, the control devices of the rock drilling rig, i.e. the memory and calculating equipment automatically take into account the deviation corresponding to the turning angle and correct, for instance, the readings of the display indicating the boom position in a way that they show the true position of the boom, such as the drill bit position and the drilling direction without the operator in practice even noticing that the correction of an error has taken place.

The invention has been presented in the above descriptions and in the drawings in the form of examples only, and it is by no means restricted to that. The essential thing is that the errors, i.e. the deviation values, affecting the drill bit position are defined as results of the various movement positions of the boom joints, boom parts, and components, and that the error is corrected on the basis of the measured deviation values, one or more movements at a time. This can be done taking into consideration all the joints or, more preferably, just the most significant errors caused by movements of joints or components on the basis of which the total error affecting the drill bit position can be sufficiently accurately calculated and then corrected with sufficient accuracy.

The deviations of each movement, i.e. the errors as a function of the joints positions can also be modelled as a continuous function over the whole travel of the movement and, thus, for e.g. turning angles as angle deviation values over the whole turning angle range. If highest possible error correction accuracy is desired, it is, naturally, necessary to define the deviation of each movement from the set value and to make the correction for each movement.

Claims

1. A method for correcting positioning errors in rock drilling, where a boom, attached from one end to a carrier and turnable in relation to it about joints, and a rock drill, mounted turnable to the other end of the boom, are arranged in the drilling position for drilling a hole in a way that the boom is controlled using control devices of the drilling rig in relation to various movements until the boom is in its set position, wherein the deviation of the boom´s actual position from the calculated theoretical position is measured, and the boom´s position is corrected on the basis of the measured deviation c h a r a c t e r i z e d in that the deviation of the boom position from the theoretical position is measured at predetermined intervals as a function of the position of at least one boom joint, that the measured deviations are stored in the memory of the drilling rig, and that when the boom and the rock drill are positioned to the drilling position, the position is corrected on the basis of the stored deviation that corresponds to the position of the joint corresponding to the said drilling position.

2. A method according to claim 1, wherein the deviation of the boom position from the calculated theoretical position is measured in the turning direction of at least one joint between the boom and the carrier.

3. A method according to claims 1 or 2, wherein the deviation of the boom position from the calculated theoretical position is measured as a function of the positions of two joints, in crossing position to one another, between the boom and the carrier.

4. A method according to claim 3, wherein the deviation of the boom position from the calculated theoretical position is measured as a function of both angles so that at the theoretical points indicating the boom position in horizontal and vertical directions at predefined intervals in a two-dimensional co-ordinate system, the deviation is defined as a function of the positions of the crossing joints.

5. A method according to any of the above claims, wherein the deviations corresponding to each joint position are measured at predefined intervals in a certain joint position value and, when positioning the boom to the drilling position, the calculated theoretical position of the boom is corrected on the basis of the deviations corresponding to the joint positions obtained in this way.

6. A method according to claim 5, wherein the deviation between adjacent, stored joint positions of each turning movement is defined by calculating an approximation for the change of deviation from one position value to the other on the basis of the measured deviations between the said joint position values.

7. A method according to claim 6, wherein the approximation for the deviation is calculated between the deviation values stored in a memory.

8. A method according to any of the above claims, wherein in addition caused by at least one other movement the deviation is measured as a function of the value of the movement sensor, and the theoretical position of the boom is corrected on the basis of the deviation corresponding additionally to this movement when positioning the boom to the drilling position.

9. A method according to claim 8, wherein on a boom equipped with a rotation mechanism for turning the rock drill together with its feed beam around an axis parallel to the drilling axis, the deviation caused by the rotation movement is measured between the true position of the boom and the theoretically calculated position of the boom, and that the position of the boom is corrected on the basis of the deviations corresponding to positions of the boom as well as the joints between the boom and the carrier, and the position of the rotation mechanism.

10. A method according to any of the above claims, wherein the deviations are stored as deviations of the drill bit position of the rock drill and deviations of the drilling direction determined by the drill steel axis.

11. A rock drilling equipment, with a carrier, a boom attached turnable about joints in relation to the carrier, a rock drill attached turnable to the other end of the boom, joint sensors indicating the positions of the various boom

joints, and control devices for controlling the boom to the drilling position for drilling a hole, c h a r a c t e r i z e d in that it includes a memory device for storing the deviations between the true position of the boom and the theoretical position calculated on the basis of the joint sensor values as a function of the turning angle of at least one boom joint, and a calculating device for correcting the boom position on the basis of the deviations stored in the said memory device and corresponding to the value indicated by the joint sensor of the said joint.

12. A rock drilling equipment according to claim 11, wherein the memory device is arranged to store the deviations between the true position of the boom and the theoretical value calculated on the basis of the joint sensors as a function of the turning angles of two to one another crossing joints between the boom and the carrier, and the calculating device is arranged to correct the boom position on the basis of the deviations, stored in the said memory unit, corresponding to the position and indicated by the joint sensors of both joints.

13. A rock drilling equipment according to claim 12, wherein the memory device is arranged to store the deviations in a two-dimensional co-ordinate system between the true position of the boom and the theoretical position calculated on the basis of the joint sensors as a function of the positions of two crossing joints.

14. A rock drilling equipment according to any of the claims 11 - 13 equipped with a separate rotating mechanism for rotating the rock drill in relation to the boom end and about an axis that is parallel with the drilling axis of the rock drill, wherein the memory device is arranged to store the deviations between the true position of the boom and the theoretical position calculated on the basis of the joint sensors, as a function of the position of the rotation mechanism, and the calculating device is arranged to correct the boom position and the turning angles of the joints between the boom and the carrier and correspondingly the turning angle of the rotating mechanism on the basis of the corresponding deviations.

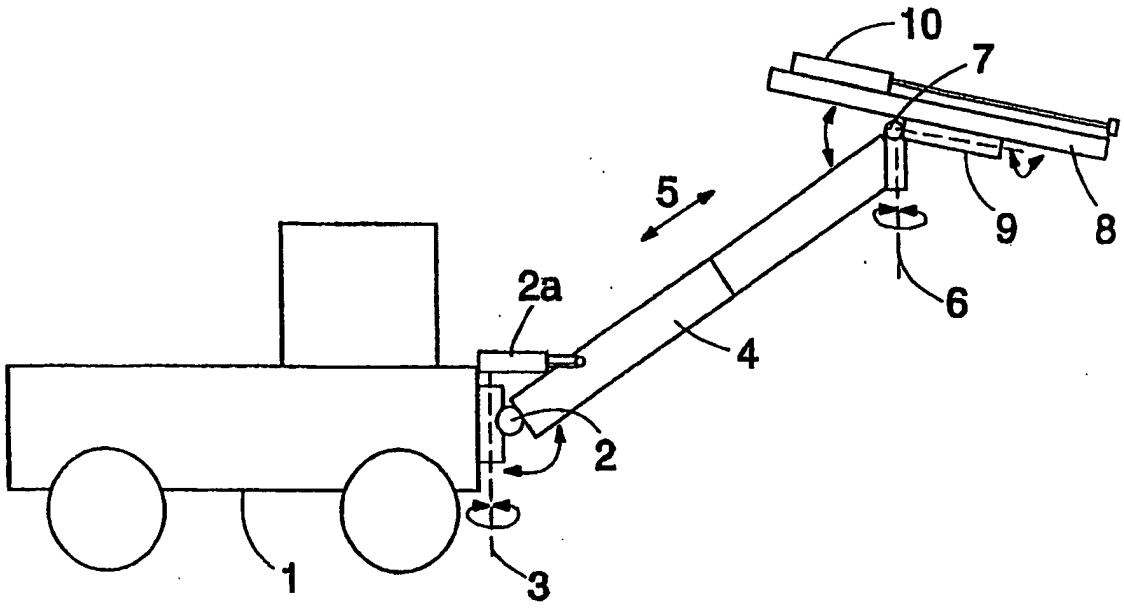


FIG. 1

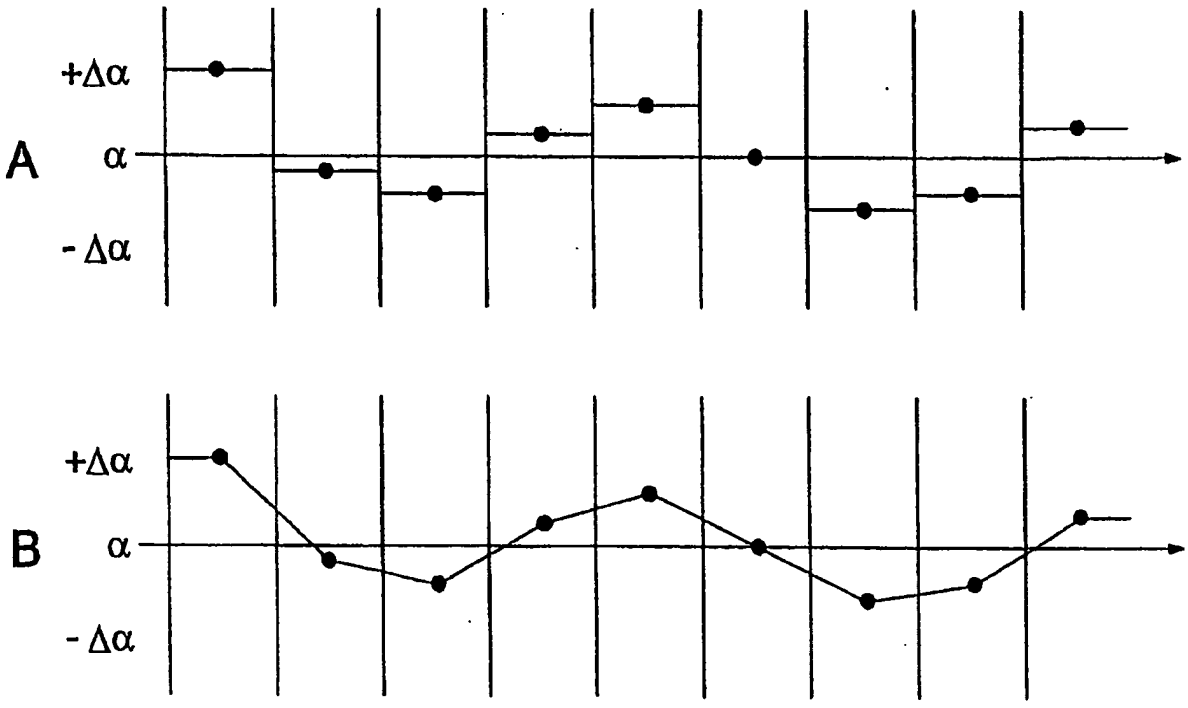


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 99/02274

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: E21B 15/00, G05B 19/404
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: E21C, E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4698570 A (O. SATOH), 6 October 1987 (06.10.87), column 1, line 33 - line 68, figure 1 --	1-14
A	US 5383524 A (H. RINNEMAA), 24 January 1995 (24.01.95), column 3, line 25 - line 32, figure 1 --	1-14
A	US 4362977 A (R.C. EVANS ET AL), 7 December 1982 (07.12.82), figure 4, abstract --	1-14
A	SE 395744 B (ATLAS COPCO AB), 22 August 1977 (22.08.77), page 6, line 1 - line 15, figure 1 --	1-14

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 March 2000	19 -04- 2000
Name and mailing address of the ISA Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Authorized officer Anna Sandberg / MR Telephone No. + 46 8 782 25 00

Form PCT ISA 210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 99/02274

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SE 395743 B (ATLAS COPCO AB), 22 August 1977 (22.08.77), page 2, line 3 - line 8, figure 1 ---	1-14
A	SE 406209 B (ATLAS COPCO AB), 29 January 1979 (29.01.79), page 16, line 1 - line 15, figure 1 ---	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

02/12/99

Inter. ional application No.
PCT/SE 99/02274

Patent document cited in search report	Publicauon date	Patent family member(s)	Publication date
US 4698570 A	06/10/87	JP 1905507 C	24/02/95
		JP 6031527 B	27/04/94
		JP 61254792 A	12/11/86
US 5383524 A	24/01/95	AU 8626291 A	28/04/92
		DE 69120279 D,T	02/01/97
		EP 0551351 A,B	21/07/93
		SE 0551351 T3	
		FI 88426 B,C	29/01/93
		FI 904937 A	09/04/92
		JP 6502000 T	03/03/94
		NO 303843 B	07/09/98
		WO 9206279 A	16/04/92
US 4362977 A	07/12/82	CA 1155519 A	18/10/83
		EP 0042960 A,B	06/01/82
		JP 57021295 A	03/02/82
SE 395744 B	22/08/77	AU 505055 B	08/11/79
		AU 8776975 A	30/06/77
		CA 1042416 A	14/11/78
		DE 2557338 A	24/06/76
		FI 753621 A	24/06/76
		FR 2296084 A,B	23/07/76
		NO 754273 A	24/06/76
		SE 7416214 A	24/06/76
		ZA 7507906 A	24/11/76
SE 395743 B	22/08/77	CA 1049491 A	27/02/79
		DE 2557048 A,C	01/07/76
		FI 67605 B	31/12/84
		FI 753592 A	20/06/76
		FR 2295214 A	16/07/76
		SE 7415975 A	21/06/76
		US 4113033 A	12/09/78
		ZA 7507665 A	24/11/76
SE 406209 B	29/01/79	CA 1092090 A	23/12/80
		GB 2000073 A,B	04/01/79
		SE 7707139 A	22/12/78
		US 4498544 A	12/02/85
		US 4499953 A	19/02/85
		ZA 7803544 A	27/06/79